Project Title: Board of Water Supply Comments on the Groundwater Modeling Working Group Meeting Held August 17, 2017 for Red Hill Administrative Order on Consent (AOC) Sections 6 and 7
Reviewer: Ernest Y. W. Lau, PE, Manager and Chief Engineer
Date: August 28, 2017

Item	Section No.	Comment
1		Thank you for the opportunity to participate in the third Red Hill groundwater modeling working group meeting held on August 17, 2017. We believe the discussion about the Navy's proposed groundwater flow and transport modeling continues to be valuable because of its technical rigor and the numerous contributions from Dr. Delwyn Oki of the United States Geological Survey (USGS), Robert Whittier of the Department of Health (DOH), and several BWS experts. We hope that the Navy and its contractors recognize the value of these contributions from Subject Matter Experts (SMEs) as they continue to develop the groundwater modeling work plan. We provide below a summary of important points from the meeting and our concerns about and recommendations for the Navy's groundwater model development.

Response: Thank you for the comments and the opportunity to respond. The Navy has always understood the importance of dialogue between Subject Matter Experts (SMEs) for the modeling initiative as well as other related activities and also believes that the discussion about the proposed groundwater flow and transport modeling continues to be valuable because of its technical rigor and the numerous contributions from SMEs including Dr. Delwyn Oki of the United States Geological Survey (USGS), Robert Whittier of the Department of Health (DOH), Don Thomas (University of Hawaii), as well as other SMEs. We recognize the value of these contributions from SMEs as we continue to develop the groundwater modeling work plan and have evaluated every suggestion from the SMEs with regard to model development that achieves the objectives of the Navy. Finally, we view BWS's attempt to describe the USGS's position on various issues somewhat out of place and ask that they confine their comments to their own opinions. If the USGS or other SMEs have an opinion on various topics, they can speak for themselves as they deem appropriate. Perhaps the best forum for this to take place would be in comments related to the Issues/Action Items Summary that are being developed for this and future meetings.

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2	Navy Preliminary Flow and Transport Model	The Navy stated that they will create a preliminary flow and transport model (preliminary model) for the Red Hill groundwater flow system that will be documented in an early 2018 technical memorandum. This "interim" memorandum is intended to provide input information for the tank upgrade alternative (TUA) study. According to AECOM, the December 2017 deadline for the preliminary model work will require the preliminary model to be developed using data available now and in the immediate term. It appears that development of the preliminary model will likely not include very important new data to be collected from the proposed installation of new Navy monitoring wells in Halawa Valley or some or all the valuable data from the ongoing USGS synoptic water level study. Furthermore, the Navy has yet to provide any information about how the sources of contaminants will be represented (source term selection) or the specifics of the transport model development. The Navy verbally agreed in the meeting to include SME review of the preliminary model and its files. The BWS reiterates its request that the Navy provide a detailed description and schedule for the development, calibration, and application of the Red Hill groundwater flow and transport model and how results from the preliminary model will be used in the TUA task. There are insufficient data currently available about groundwater flow paths and aquifer properties in Halawa Valley between Red Hill and our Halawa Shaft to build a credible flow and transport model. A considerable amount of additional field data are necessary to develop a conceptual site model (CSM) for current critical areas of concern and past/future Red Hill contamination; to construct a defensible approach to simulate groundwater transport, and to quantify uncertainty in the transport predictions. The BWS has repeatedly pressed for such data to be collected and welcome the Navy's proposed new monitoring wells in Halawa Valley. However, our oft-stated concern about the defensibility of any model built without these necessary data remains unchanged. We ask that the regulatory agencies ensure timely technical review of the preliminary model and its files by SMEs before the preliminary model results are used or reported.

Response: There are decisions that need to be made in a timely fashion in order to meet the timetable in the AOC for the Tank Upgrade Alternatives (TUA) decision. Results from the Interim modeling will be used to help inform decisions related to the TUA. If additional data are not available by the time the preliminary model is being developed, then they cannot be incorporated into the model, and decisions need to be made with the information that is available. This is why the Navy is proceeding as fast as possible in collecting new data in order to address this concern. The Navy will be simulating a range of conditions for valley fill (as described in the Groundwater Model Evaluation Plan). This was previously done as a sensitivity analysis by Oki (2005). As more data becomes available relative to valley fill, it will be integrated into the model. The Groundwater Model Evaluation Plan that was recently submitted by the Navy also generally describes how fate and transport will be dealt with in the modeling process. Much of this was verbally discussed during the last stakeholder meeting and will continue to be discussed at future meetings. The Navy will continue to consider stakeholder input on these efforts as we go forward.

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3	Development of the Numerical Groundwater Flow Model	Much of the meeting's discussion focused on how the interactions between fresh groundwater and denser seawater should be represented in the Navy's model. These discussions made it plainly evident that the USGS, DOH, and BWS modeling experts disagree with the approach proposed by Dr. Sorab Panday, the Navy's modeling consultant (GSI Environmental, subcontractor to AECOM). Dr. Oki of the USGS and BWS experts expressed serious doubts that Dr. Panday's approach would provide a sufficiently accurate representation of the simple flow physics of fluids with varying densities. Dr. Oki suggested that Dr. Panday perform several simple model simulations that would show the bias and errors of his approach, but Dr. Panday would not agree to do so. The BWS supports Dr. Oki's suggestions and believes that a potentially important aspect of the Navy's model is an ability to simulate the evolution and changes of the thickness in the fresh water zone over time. We request that the regulatory agencies ask the Navy to demonstrate that their approach of not simulating density- dependent flow will not bias estimates of groundwater levels and flow rates over time within the model domain. Such a demonstration should begin with Dr. Oki's suggested test simulations. It appears that the Navy is planning to calibrate the groundwater flow model to observe groundwater levels and spring flows for the period from 2014 to the near present. Both the USGS and BWS are concerned that this length of time for demonstrating agreement between observations and model predictions is too short, even if the Navy includes a several year start-up period. Available groundwater level observations in the area of interest during this short period are very sparse and limited to only a few locations, which means the calibration will contain high uncertainty about the large model areas without any groundwater level observations. This high uncertainty can be reduced by calibrating over a longer time period, such as the calibration period used in Oki (2005). Both the USGS and BWS suggested that the Navy calibrate over the same time period used in Oki (2005) so that the Navy can: 1) reduce uncertainty about groundwater level predictions in large portions of the model; and, 2) generate a more defensible estimate of groundwater levels across the entire model area for present conditions. The BWS requests that the regulatory agencies direct the Navy to extend the calibration period to match that used by Oki (2005) in order to reduce uncertainties in model predictions. Dr. Sorab Panday and BWS experts agreed it is very important that the Navy include the effects of uncertainty on predictions from the groundwater flow and transport models using best modeling practices. Specifically, it was agreed that the Navy formally investigate the impacts of uncertainty in model components (boundary conditions, aquifer properties, initial conditions, etc.) on model predictions using constrained uncertainty analysis. BWS strongly recommends that the regulatory agencies direct the Navy to include such analyses as a required part of the CSM and the calibration and application of the flow and transport model. Mr. Mark Manfredi agreed that the Navy will provide the input and output files for the Navy preliminary and final groundwater flow and transport models to the BWS and other SMEs for technical review. The BWS appreciates the Navy's agreement and requests that the Navy's contractors include suitable times for SME review in their schedules for model development. AECOM agreed to provide a detailed schedule for the groundwater model development (both preliminary and final) in the next groundwater modeling working group meeting to be conducted the week of September 18, 2017. The Navy stated that it will include measured flow rates at Kalauao Springs and spatially varying recharge as part of its model development. Using spatially-varying recharge rates such as those from Engott et al. (2015) will likely improve the model's ability to

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		predict groundwater levels. Comparing simulated and observed spring flow rates will also help improve the calibration of the groundwater flow model.

Response: The comment states that "there are serious doubts that Dr. Panday's approach would provide a sufficiently accurate representation of the simple flow physics of fluids with varying densities" and that "important aspect of the Navy's model is an ability to simulate the evolution and changes of the thickness in the fresh water zone over time". However, as indicated in our response to comments on the June 26, 2017 meeting and in the presentation used for the August 17, 2017 meeting, our objective is not about flow of fluids with varying densities which lies hundreds of feet below the water table surface. Also, as detailed in our response to comments, the Oki (2005) model showed that the impact of pumping on the interface was small and such small changes in salinity have a negligible impact on the simulated transmissivity of the freshwater aquifer.

This is another example of how the Navy takes the comments of the SMEs very seriously. However, upon further analysis, several issues with running the SWI2 module of MODFLOW for this project were uncovered as we disclosed in the August 2017 meeting. We further evaluated and suggested two alternatives (including pros and cons) that have been commonly used to evaluate groundwater flow and solute transport in coastal systems when saltwater evaluations are not the objective of the analyses. Please see the response to comments on the June 26, 2017 meeting.

The two approaches presented include the preferred approach which was to provide equivalent freshwater heads along the coastal boundary to conceptualize the deeper saltwater intrusion that occurs from the sea floor. This methodology is not novel and Dr. Panday has used this approach in modeling coastal aquifer systems during his career. Publications by Dr. Motz from the University of Florida also provide a validation of this approach for approximating the hydraulic heads in freshwater portions of a coastal aquifer (Motz, 2004; Motz and Sedighi, 2006).

Dr. Panday was reluctant to perform experiments for fear that one could lead to another and then another which would then divert focus from the project. While we did seriously consider the expected results of running these simulations, this is now immaterial since we have decided to use another approach, as discussed below.

In considering discussions from SMEs detailed in the August 2017 meeting, the Navy has had further internal discussions. It was clear in the meeting that the issue was not about the movement of the saltwater/freshwater interface beneath the pumping wells and was really about the reduction in freshwater transmissivity near the coast due to the presence of the interface. After all, the interface is over 800 feet below the pumping zone and there is a large horizontal anisotropy. Therefore, we will use the other approach discussed during the August 2017 meeting for simulating freshwater flow in coastal aquifer systems. This method provides a no-flow boundary across the saltwater interface. This approach also captures the freshwater transmissivity zone using a constant density model like MODFLOW. The method is also widely applied for simulating coastal aquifers when saltwater intrusion itself is not the objective. It has been successfully used in Hawaii for example, by Glenn et al, 2013; Ghazal et al, 2017, Whittier et al, 2010, Whittier et al, 2015. This approach is also used for modeling coastal aquifer systems elsewhere. For example, prominent researchers at the USGS have used MODFLOW-2005 in a similar setting to conditions of the Red Hill model, whereby their objective was to delineate capture zones in a coastal aquifer system (Brakefield et al, 2013). A search of USGS Florida Water Science Center Publications itself shows several constant density models being used in coastal aquifer systems when saltwater intrusion is not the objective as in the Red Hill Model case. As another example, the publication by Paschke (2007) contains several examples of MODFLOW models developed in coastal or saline settings to evaluate transport of contaminants including two in the Tampa area, and one in the Salt Lake Valley area. Conversely, we have not come across any publication that includes density dependent saltwater intrusion processes for investigations that do not directly focus on saltwater interactions (i.e., solute transport analyses). We are therefore following a defensible approach for groundwater flow, particle tracking and transport simulations, which has been previously used, tested, published, and is widely accepted by the scientific community.

At the August 2017 meeting, we presented a model calibration strategy that uses annual average steady-state

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flow conditions similar to current conditions. The resulting steady-state flow model will be used to evaluate long-term strategies. We also presented a model calibration strategy for shorter-term seasonal transient conditions, if such data are available. The Navy would use such a model for scenario evaluations related to transient (shorter-term) conditions and changes. We suggested an initialization approach for the transient simulations with a 1-year initialization period. The only objection we heard to this strategy at the meeting was to use a longer initialization period, to which we agree, if that is needed. For the simulation of long-term steady-state conditions, we will use all available pertinent data including historical data to calibrate the model so that no pertinent data will be ignored. We will review, evaluate, and where appropriate, utilize long-term water level trends and extrapolate older data within the model domain onto the current time-frame incorporating all available information. A higher weight will be assigned to the recent synoptic water level data during model calibration and a lower weight will be applied to the extrapolated older data.

While there was discussion on the topic of model uncertainty at the August 2017 meeting, Dr. Panday did not agree that "*it is very important that the Navy include the effects of uncertainty on predictions from the groundwater flow and transport models using best modeling practices. Specifically, it was agreed that the Navy formally investigate the impacts of uncertainty in model components (boundary conditions, aquifer properties, initial conditions, etc.) on model predictions using constrained uncertainty analysis*". Rather, Dr. Panday only agreed that use of constrained uncertainty analysis will be evaluated and specifically noted that he does not commit to anything without discussions with and consent of the Navy. This issue is being further discussed with the Navy and a decision will be forthcoming.

The model codes are publicly available. In addition, the model GUI (GMS) is proprietary and is available for sale. The GIS database will be continued to be updated and SMEs (including BWS) will be provided with those updated databases as they become available, once the associated security issues are addressed (as discussed in our last meeting). Furthermore, BWS must agree to not change any of the data in the GIS database without the Navy's approval and that all sensitive data will be secured from the public domain.

Model input and output files will not be provided until the model is finalized and security issues are addressed (as we discussed in the last meeting related to preventing sensitive information from being released to the public). Furthermore, the model input files may be provided with the following caveats: 1) BWS agrees that they will not change any of the input data without concurrence from the Navy and that all data is secured from the public domain, and 2) although not agreed to in the meeting, the Navy may agree to running a reasonable number of scenarios at BWS's request after the model is calibrated for which the Navy will provide output. Finally, the Navy will also request that any model input/output files being run by BWS and their consultants also be provided to the Navy for evaluation. The Navy is under an extremely tight deadline for finalizing model development and currently intends to submit the model results in mid-January 2018. In order to minimize possible issues with model development, the Navy is fully committed to meeting with SMEs on a regular basis to discuss various modeling issues in an effort to keep an open communication throughout the process.

The Navy will provide a general schedule for development of both the preliminary and final groundwater models at the next Groundwater Modeling Working Group Meeting scheduled for September 22, 2017.

Available flow rates for springs (including Kalauao Springs) and spatially varying recharge rates within the modeling domain will be used as appropriate in the development and calibration of the model.

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4	Development of the Groundwater Transport Model	Dr. Sorab Panday proposed to use the MODFLOW-USG (unstructured grid) flow code to simulate groundwater flow and a currently unverified USG transport code to simulate migration of groundwater contaminants. The MODFLOW-USG flow code has been tested for numerous cases over the last several years and its documentation and source code have been available from the USGS for review over that same period, all of which make it a suitable choice for flow simulation. The BWS has serious concerns about the suitability of the USG transport code for the Red Hill project. According to Dr. Panday, the USG transport code has been applied to only two projects, for which there are no final reports available for review, and the source code and documentation will only be made available in September 2017. This means that the Navy's recommended modeling tool to predict migration of contaminants (transport) will have undergone very limited review and testing prior to being used for the Red Hill modeling, raising the possibility of significant errors in model predictions. Moreover, GSI has not demonstrated that the model input and output files can be easily and accurately modified and visualized using conventional MODFLOW interfaces such as Groundwater Vistas or Groundwater Modeling Systems (GMS). The BWS recommends that the regulatory agencies and the Navy avoid using MODFLOW-USG transport and instead adopt a very well tested and understood transport code paired with a suitable groundwater flow code. The combination of codes should also correctly simulate the variable density interactions between freshwater and seawater.
Response: The Navy conducted a careful analysis for the use of different models and presented a table describing the pros and cons for various potential models as they relate to the Navy's modeling objective. The Navy has selected MODFLOW-USG for the reasons we discussed during the August 2017 meeting since this code best allows the Navy to meet its modeling objectives. The transport module within MODFLOW-USG using unstructured grids has been available within the Groundwater Vistas Interface for several years now and may have been used more by others unbeknown to us. Testing of the transport modules of USG-Beta is admittedly limited and therefore the Navy will test the modules against results from MODFLOW-NWT / MT3D for the same hydrogeologic setup as with MODFLOW-USG. As discussed at our August 2017 meeting, all 3 codes which were discussed are available within the GMS framework and therefore conversion from one set of codes to another is straightforward. The advantages of proceeding with MODFLOW-USG were discussed at the August 2017 meeting and include robust and efficient simulations for developing and calibrating the Red Hill model.		

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